Nuclear Power Plant Accidents Notes

This presentation addresses the Three Mile Island, Chernobyl, and Fukushima nuclear power plant accidents.

Slides 3 – TMI-2 reactor plant schematic

- slide shows major structures to be reactor containment building, auxiliary building, turbine building, and dual cooling towers
- entire reactor coolant system, including steam generators, enclosed by reactor containment building
- emergency core cooling system (ECCS) core flood tanks located in reactor containment building
- ECCS high pressure injection pumps, located in auxiliary building, pump water from borated water storage tank into reactor coolant inlet piping
- steam cycle power plant located in turbine building

Slide 4 – TMI primary coolant system

- graphic shows plant's reactor coolant system (RCS), consisting of steam generators for heat removal and pressurizer for control of RCS pressure
- RCS pressure must be maintained above 2000 psia for PWR to keep water subcooled (below boiling point for reactor operating temperature)
- RCS pressure controlled by maintaining high-temperature, high-pressure steam "bubble" in pressurizer (water incompressible, but size of steam bubble can be controlled by adjusting steam bubble pressure at constant temperature)

Slide 5 – TMI condensate and feedwater systems

- steam generators in schematic remove heat from nuclear reactor by transferring heat from high pressure reactor coolant on primary side to low pressure water on secondary side
- feedwater system provides low pressure water to secondary side of steam generators
- schematic shows plant's secondary coolant system (i.e., steam cycle power plant), where accident initiating event occurred (shown in red at lower right)
- plant components necessary for continued reactor heat removal, and circumstances that led to their unavailability, also shown in red
  - blockage occurred in condensate polisher (water treatment) unit that reduced water flow to main feedwater pumps
  - when main feedwater pumps tripped offline due to low suction pressure, normal feedwater flow to secondary side of steam generators was lost

    - at this point, emergency feedwater (EFW) flow to steam generators should have commenced
    - however, normally-open EFW block valves were closed (due to human error when scheduled maintenance performed on EFW system 2 days before accident)
  - block valve closures not recognized for first 8 minutes of accident

Slide 8 – TMI reactor coolant system 8 minutes into accident graphic

- graphic shows condition of RCS at 8 minutes into accident
- loss of feedwater flow to secondary side of steam generators terminated heat removal from RCS
- resulting increase in RCS pressure caused automatic reactor shutdown and opening of PORV to relieve excess RCS pressure
- because PORV failed to re-close after RCS pressure reduced, pressurizer steam bubble was lost
- failure of PORV to re-close resulted in continuing loss of reactor coolant water; directed to containment building quench tank
- when quench tank became full, tank rupture disk burst and water then flowed to containment building sump

Slide 11 – TMI-2 core end-state configuration

- slide illustrates final reactor core configuration at termination of TMI Unit 2 accident
- top half of reactor core overheated and melted
- melted fuel and core structure (called corium) that slumped to bottom of reactor vessel did no damage to vessel

Slide 18 – Chernobyl RBMK reactor graphic

- graphic is illustration of Russian RBMK reactor
- faulty reactor design that couldn’t be licensed to operate outside Soviet Union
    - no reactor containment building
    - positive void reactivity coefficient in low power range
    - very large reactor core with risk of neutronic behavior becoming uncoupled

Slide 19 – Chernobyl RBMK reactor graphic (cont.)

- graphic an illustration of RBMK reactor coolant system
- fuel elements contained within pressure tubes located within channels through graphite moderator
- cooling water flowing through pressure tubes boils to create steam, which is collected in steam drums before being directed to plant’s steam turbines
- control rod channels, cooled by independent water circuit, also located within channels through graphite moderator

Slide 20 – Chernobyl accident sequence

- two compelling reasons why test should not have been performed
  - — test required that some safety systems be bypassed
  - — reactor had positive void reactivity coefficient in low power region where test was to be performed
- positive feedback condition amplified power increase, causing 2.7-fold increase in reactor power in less than 0.1 second
- even automatic control rod insertion couldn't have prevented destructive power excursion

Slide 21 – Chernobyl accident graphic

- when 2,000-ton upper biological shield was lifted, it destroyed coolant piping and control rods in graphite moderator
- shrapnel from explosion penetrated reactor compartment concrete walls

Slide 22 – Chernobyl post-accident photo

- photograph of 4-unit Chernobyl nuclear power plant shortly after accident at Unit 4 (foreground)

Slide 23 – Chernobyl post-accident photo (cont.)

- photograph shows Unit 4 destruction caused by accident

Slide 24 – Chernobyl accident radiological consequences

- 38 years after accident, no adverse health effects observed for those within 30-km evacuation zone
- data collected since 2000 by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) show incidence of all cancers combined in exposed population was 2 to 70 per cent lower than in non-exposed populations of Ukraine, Belarus, and Russia

Slide 25 – fewer observed cancers from Chernobyl radiation exposures

- increased number of thyroid cancers detected in contaminated area populations shortly following accident not in agreement with thyroid cancer latency of 8-10 years after irradiation – likely due to dramatic changes in diagnostic services that came about because of accident

Slide 26 – Chernobyl accident radiation dose comparisons

- slide shows <u>lifetime</u> (cumulative) natural background doses in several European countries and in Chernobyl regions of low, medium, and high radioactive material contamination levels
  - — note that <u>cumulative</u>, chronic low doses are meaningless because they deny body's prevention, repair, and removal adaptive protection mechanisms
  - — nevertheless, histogram clearly indicates that decisions to evacuate hundreds of thousands of inhabitants from 30-km (18.6 mile) evacuation zone unwarranted

Slide 27 – Chernobyl reactor and surrounding area current status

- in spite of fallacious reports of radiologically-induced wildlife mutations, no adverse effects observed in local wildlife

Slide 28 – Chernobyl Unit 4 new safe confinement structure photo

- New Safe Confinement, completed in 2018, designed to confine solid radioactive remains of accident for next 100 years

Slide 30 – Fukushima accident

- Initiating event – tsunami that exceeded plant design basis
  - magnitude 9.0 earthquake occurred 130 km off eastern coast of Honshu Island that created 23-meter-high tsunami at point of origin
  - Fukushima Daiichi reactors automatically shut down by seismic sensors
  - plant design basis tsunami height was 5.7 meters and plant built approximately 10 meters above sea level
  - tsunami height greater than 14 meters when it reached plant sea wall

Slide 31 – Fukushima Units 1-4 BWR design graphic

- Units 1-4 had Mark I pressure suppression containment structures consisting of drywell (primary containment) and wetwell (suppression pool or torus)

Slide 32 – tsunami size as accident cause graphic

- 2011 tsunami was beyond-design-basis event for Fukushima Daiichi nuclear power plant
- earthquake caused loss of offsite electrical power
- plant emergency diesel generators located below grade in each unit’s turbine hall, making them susceptible to flooding events
- when tsunami breached plant’s sea wall, all onsite emergency electrical power submerged, resulting in station blackout

Slide 33 – Fukushima accident sequence

- new knowledge regarding likelihood of large earthquake and resulting major tsunami revealed in 1993
- despite recommended tsunami countermeasures such as moving emergency diesel generators to elevation above plant ground level, no action taken by either plant owner (Tokyo Electric Power Company) or Japanese nuclear plant regulator (Nuclear & Industrial Safety Agency)
- when tsunami came over plant’s sea wall, it destroyed emergency diesel fuel storage tanks, which also rendered emergency diesel generators inoperable
- with loss of both offsite and emergency onsite power plant experienced station blackout

Slide 35 – Fukushima plant photo prior to tsunami

- photograph shows Fukushima Daiichi Units 1–4 (right to left, circled in red) prior to accident
- emergency diesel fuel storage tanks in lower right corner of photograph (circled in orange)
- ultimate heat sink service water systems (circled in blue)

Slides 36 – Fukushima plant photo after tsunami

- note missing emergency diesel fuel storage tanks along with almost everything else just behind plant's seawall, including ultimate heat sink service water systems (circled in red)

Slide 37 – secondary containment building photos before and after hydrogen explosion

- hydrogen gas from oxidation of nuclear fuel cladding vented from reactor containment structures, which in absence of power for reactor building ventilation system collected in upper part of each reactor building
- when hydrogen reached flammability limit it ignited, with explosion blowing off roof of reactor building as shown in photographs

Slide 38 – Fukushima plan photo after hydrogen explosions

- hydrogen explosions occurred in Unit 1, 3, and 4 reactor buildings as shown in photograph

Slide 39 – Fukushima accident radiological consequences

- about 18,000 people died from tsunami on March 11, 2011
- no one suffered adverse health effects due to radiation exposure from damaged reactors
- real health consequences of accident from unwarranted evacuations required because of irrational fear of low-level radiation
- more than 1600 people died from evacuation-induced stress that exacerbated existing health problems, produced life-shortening severe depression, or prompted suicide
- after more than 10 years, very few people allowed by Japanese authorities to return to homes or businesses because of irrational fear of low-level radiation

Slide 40 – Fukushima contaminated water control graphic

- graphic shows ice walls and sub-drains constructed to control radioactively-contaminated water leakage from reactor and turbine building basements to sea
- contaminated water collected for purification

Slide 41 – Fukushima current plant status

- note that tritium is isotope of hydrogen and cannot effectively be removed from water

- emits extremely low energy beta particle as it decays to stable helium-3
- not legitimate health hazard even if ingested because it does not concentrate in any body organs or tissue

- although there were many anti-nuclear voices opposing release of collected tritiated water to Pacific Ocean, that is only efficient disposal method available
  - tritiated water very quickly diluted and poses no risk to aquatic life
  - release of tritiated water to Pacific Ocean began in August 2023

Slide 42 – Fukushima current plant status (cont.)

- photograph shows contaminated water storage tanks at Fukushima plant site

Slide 46 – Fukushima – beyond design basis?

- 2011 tsunami that struck Fukushima nuclear plant, with actual wave height of about 15 meters, was beyond plant's authorized design basis
  - question is, should it have been considered design-basis event (e.g., 100-year tsunami)
  - design basis events evaluated for Fukushima plant could, in hindsight, be considered deficient since 1896 tsunami exceeded plant's documented design basis tsunami
- raises question, how unlikely should occurrence of event be for exclusion from design basis of any nuclear power plant (i.e., identified as beyond-design-basis event that requires no specific risk mitigation)
- might be considered prudent to have included 100-year tsunami in Fukushima nuclear plant's design basis, but what about 500-year tsunami or 1,000-year tsunami – where does one draw line with regard to designing plant to withstand very low-probability natural phenomena events

Slide 47 – occurrence of low probability events

- likelihood of event's occurrence, especially natural phenomena event, means that over very long periods of time one can expect, on average, to observe event occurring with specified frequency – event's likelihood of occurrence
  - 500-year or 1,000-year tsunami could occur anytime, or perhaps even twice in next 12 months
  - question is, what tsunami should be used as design basis event for nuclear power plant located near the ocean
- how does one trade off cost associated with preventing significant damage from very low probability event versus benefit lost from not providing affordable, reliable electricity due

to unwillingness to accept low-probability risk associated with event's occurrence
  - there is cost/benefit issue associated with all low-probability risks

Slide 48 – risk acceptability

- slide addresses very emotional issue of risk acceptability
- many people want to invoke Precautionary Principle as sufficient reason to ban construction and operation of nuclear power plants based on potential risks associated with very low-probability natural phenomena
- need to remember that except for adverse health consequences caused by irrational fear of low-level radiation, no one was harmed by TMI and Fukushima accidents
- if society unwilling to accept very low-probability risks, or bear increased costs associated with bringing all conceivable risks into nuclear power plant's design basis, then abundant, affordable, reliable electricity may, at some point, become historical artifact